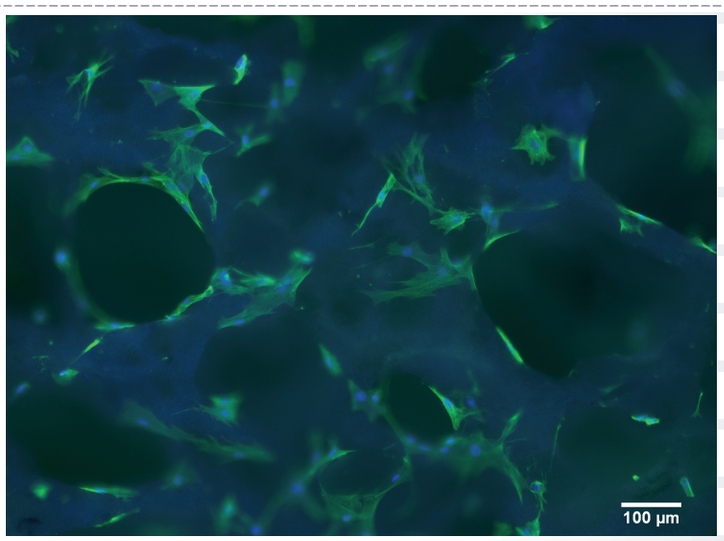
DEPARTMENT OF COMPOSITES AND CARBON MATERIALS

INSTITUTE OF ROCK STRUCTURE AND MECHANICS
of the Czech Academy of Sciences

THEMATIC RESEARCH FOCUS

- **MODERN FIBROUS, PARTICULATE AND HYBRID COMPOSITE MATERIALS ON THE BASIS OF SYNTHETIC OR NATURAL MATERIALS**
- **COMPOSITE MATERIALS FOR MEDICAL USE**
- **HEAT RESISTANT COMPOSITES**



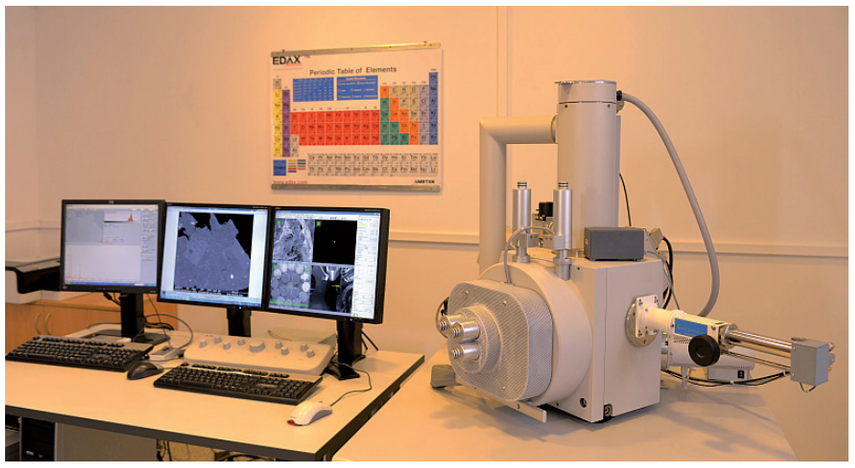
Human mesenchymal stem cells cultured on a porous composite scaffold based on collagen matrix, polylactide nanofibers, calcium phosphate nanoparticles and sodium hyaluronate.

MAIN RESEARCH SUBJECTS

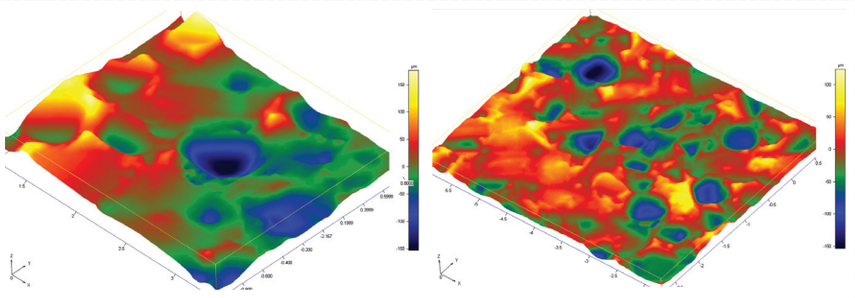
- Advanced composite materials for medical applications in the form of bone graft replacements, substitute/filling, or connective elements, are designed on the basis of biocompatible and biodegradable matrices and various kinds of reinforcing phases in the form of micro and nano fibers or particles. Individual components and composites are prepared by electrospinning, lyophilisation and further common curing and precipitation techniques. Long-standing experience with collagenous materials and calcium phosphates isolated from natural precursors are applied in their preparation. Physico-chemical characterization and quality of particular precursors are monitored by FTIR spectro-scopy, X-ray diffraction, chemical analyses, SEM, TEM and EDS. The ability of composites to create a strong connection with bone tissue is further optimized with the help of specially developed techniques, enabling creation of open, interconnected pores of suitable dimensions and density for bone cell ingrowth.
- Micro- and nano-structures of composites and their precursors are observed by optical and electron microscopy and quantitatively evaluated by methods of image analysis. The influence of physical and chemical properties of composites on suitable structural and functional connections with bone tissue are evaluated. Topography of their surfaces (standard roughness parameters, dimensions, shape and density of pores) is evaluated by a non-contact 3D measuring device. The biological evaluation of composites is carried out by testing in simulated body fluid and by tests ***in vitro*** and ***in vivo***, in cooperation with other departments. Macro-mechanical and micro-mechanical properties are studied using a universal testing device and by nano-indentation. Dynamic mechanical properties are studied using a resonant frequency method.
- Composites for medical instrumentation or targeting devices are also being studied for use in medicine. Comprehensive fundamental research is carried out on various kinds of modifications of composites, based on various fibers and polymer matrices, in an attempt to improve their mechanical, structural and chemical stabilities after repeated sterilization by widely-used techniques.
- The laboratory of composite materials is also engaged in the development of composites designed for exposure in applications at elevated temperatures. The research focuses on polysiloxane matrix precursors and its thermally induced conversion to silicon oxycarbide. This ceramic material has a high thermal resistance and low density and, therefore is being tested as a fire resistant foam core of sandwich structures or matrices reinforced by ceramic or basalt fibres. The laboratory is equipped with the Inspekt 100 universal testing machine with load preparations, extensometers and a Maytec furnace for measuring mechanical properties of materials at temperatures up to 1500 °C.

KEY RESEARCH EQUIPMENTS

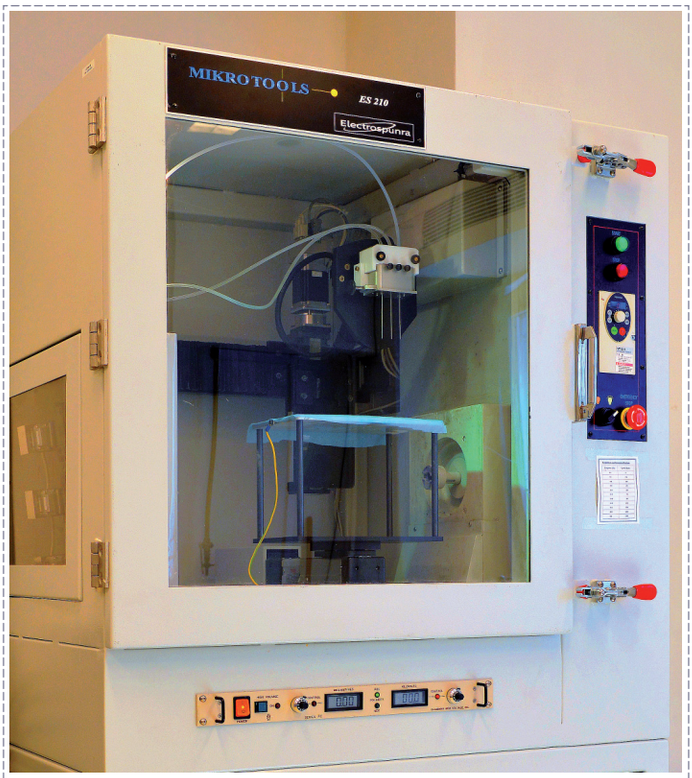
- Electrospunra ES-210 (Mikrotools)
- Quanta 450 (FEI) scanning electron microscope with SE, BSE CI, GAD, cathodoluminescence and EDS SDD EDAX detectors
- Nicolet Protégé 460 E.S.P. (Thermo-Nicolet) Fourier transform infrared spectrometer
- Inspekt 100 universal testing machine (Hegewald & Peschke)
- MarSurf TS 50/4 (Mahr) non-contact surface measurement
- Clean room equipped with laminar flow cabinet, UV sterilization, centrifuges, a freeze drier (VirTis 4KZL) and a DH CO_2 incubator (Thermo Scientific)
- Image analysis laboratory equipped with Nikon Optishot 100S (Nikon) microscope supplemented with a ProgRes (JENOPTIK) color digital microscope camera and an AR system (Nikon) NISelement.
- HLV 5.1 (Pracovní stroje Teplice) hydraulic molding press
- HTK 8 GR/22-1Gman (GERO) high temperature graphite furnace
- Polydrive mixer HAAKE R600 (Thermo Electron Scientific)



Quanta 450 (FEI) scanning electron microscope



3D scan of porous surface carried out by non-contact topography mesurement (MarSurf TS 50/4, Mahr)



Electrospunra ES210 - capable of producing micro and nano fibers

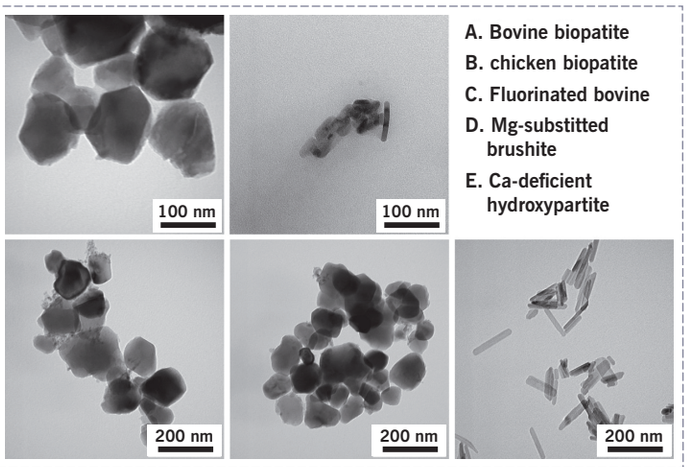
Inspekt 100 universal testing machine

ACHIEVEMENTS

● Isolation, characterization and application of calcium phosphates nanoparticles from various animal genera and sources

M. Šupová, GS. Martynková, Z. Sucharda. *Bioapatite made from chicken femur bone.* Cera-mics-Silikaty 2011; 55:256-60.

M. Šupová. *Isolation and preparation of nano-scale bioapatites from various natural sources: a review.* Journal of Nanoscience and Nanotechnology 2014; 14:546-63.

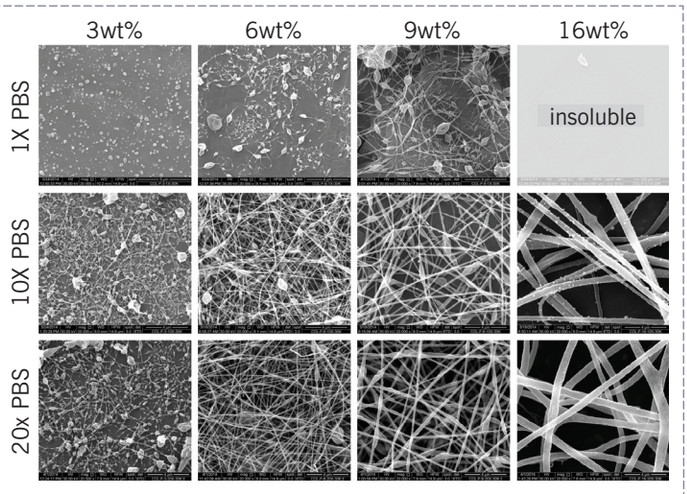


A. Bovine biopatite
B. chicken biopatite
C. Fluorinated bovine
D. Mg-substitted brushite
E. Ca-deficient hydroxypartite

An example of calcium phosphates nanoparticles isolated from various animal genera and sources (A, B, C) and prepared by precipitation (D, E).

● Preparation of nanofibers based on natural polymers (collagen, gelatin, polylactides) and hybrid nanofibers added with calcium phosphate nanoparticles

K. Novotná, M. Zajdlová, T. Suchý, D. Hadraba, F. Lopot, M. Žaloudková, TEL. Douglas, M. Munzarová, M. Juklíčková, D. Stránská, D. Kubies, D. Schaubroeck, S. Wille, L. Balcaen, M. Jarošová, H. Kozák, A. Kromka, Z. Švindrych, V. Lisa, K. Balík, L. Bačáková. *Polylactide nano-fibers with hydroxyapatite as growth substrates for osteoblast-like cells.* Journal of Biomedical Materials Research Part A 2014; 102(11):3918-30.



SEM images of collagen nanofibers (type I, isolated from carp skin) illustrate optimization of collagen solutions from electrospinning.

● High performance radiolucent composite materials providing resistance against sterilization decomposition

T. Suchý, R. Sedláček, Z. Sucharda, K. Balík, T. Bouda. *Effects of thermal ageing on the static and cyclic mechanical properties of carbon fibres/PDMS composites for use in medicine.* Computer Methods in Biomechanics and Biomedical Engineering 2013; 16:255-7.

R. Sedláček, T. Suchý, Z. Sucharda, K. Balík, M. Sochor, J. Šepitka, J. Lukeš. *The influence of sterilization processes on the micromechanical properties of polyamide fiber-reinforced PDMS composites for orthopaedic applications.* Computer Methods in Biomechanics and Biomedical Engineering 2012; 15:91-2.

T. Suchý, K. Balík, R. Sedláček, Z. Sucharda, M. Sochor, J. Prokop, J. Beneš, J. Křena. *Radiolucent composites providing high resistance against sterilization decomposition.* Ceramics-Silikáty 2011; 55(4):401-9.

Carbon/PPS composite intraoperative guides for accurate targeting of the distal nail holes and accurate interlocking screws used for the treatment of diaphyseal fractures of long bones.

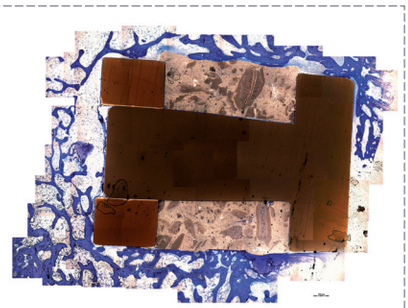
● Composite materials for bone tissue engineering

T. Suchý, Š. Rýglová, K. Balík, K. Smetana, M. Šupová, Z. Sucharda, E. Filová, J. Havlíková, L. Bačáková, GS. Martynková. *Biological evaluation of polydimethylsiloxane modified by calcium phosphate nanoparticles for potential application in spine surgery.* Science of Advanced Materials 2013; 5(5):484-93.

E. Filová, T. Suchý, Z. Sucharda, M. Šupová, M. Žaloudková, K. Balík, V. Lisá, M. Šlouf, L. Bačáková. *Support for the initial attachment, growth and differentiation of MG-63 cells: a comparison between nano-size hydroxyapatite and micro-size hydroxyapatite in composites.* International Journal of Nanomedicine 2014; 9:3687-706.

V. Pešáková, K. Smetana, M. Sochor, H. Hulejová, K. Balík. *Biological properties of the intervertebral cages made of titanium and containing a carbon-carbon composite covered with different copolymers.* Journal of Material Science. Materials in Medicine 2005; 16(2):143-8.

V. Pešáková, Z. Klezl, K. Balík, M. Adam. *Biomechanical and biological properties of the implant material carbon-carbon composite covered with pyrolytic carbon.* Journal of Materials Science. Materials in Medicine 2000; 12(11):793-98.



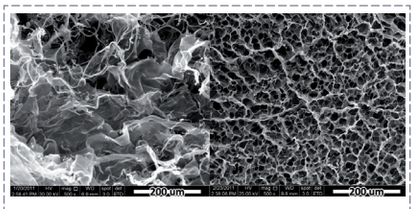
Illustrative histological composite micrograph of a cylindrical implant (particulate composite, PDMS/nanoHA) ingrown into the original bone of an animal model (stained by trypan blue, mag. 5x).

MAIN COLLABORATING PARTNERS

- University of Vienna, Institute of Materials Physics, (Vienna, Austria)
- National University of Singapore, (Singapore)
- Indian Institute of Technology Madras, Medical Materials Laboratory, (Chennai, India)
- AGH University of Science and Technology, (Krakow, Poland)
- Institute of Macromolecular Compounds, Russian Academy of Science, (St. Petersburg, Russia)
- Czech Technical University in Prague (Prague, CZ)
- Institute of Chemical Technology Prague (Prague, CZ)
- Technical University of Liberec (Liberec, CZ)
- Institute of Inherited Metabolic Disorders 1st FM, Charles University in Prague (Prague, CZ)
- Faculty of Medicine in Pilsen, Charles University (Pilsen, CZ)
- Institute of Anatomy First Faculty of Medicine Charles University in Prague (Prague, CZ)
- Institute of Physiology AS CR, v.v.i. (Prague, CZ)
- Institute of Animal Physiology and Genetics AS CR, v.v.i. (Liběchov, CZ)
- Institute of Macromolecular Chemistry AS CR, v.v.i. (Prague, CZ)
- Institute of Organic Chemistry and Biochemistry AS CR, v.v.i. (Prague, CZ)
- Institute of Physics of Materials AS CR, v.v.i. (Brno, CZ)
- Elmarco, s.r.o. (Liberec, CZ)
- ProSpon, s.r.o. (Kladno, CZ)
- Contipro Group, s.r.o. (Dolní Dobrouč, CZ)
- MEDIN, a.s. (Nové Město na Moravě, CZ)
- MEDIN Orthopaedics, a.s. (Prague, CZ)
- LA Composite, s.r.o. (Prague, CZ)
- LATECOERE Czech Republic s.r.o. (Prague, CZ)
- National Radiation Protection Institute, v. v. i (Řež, CZ)

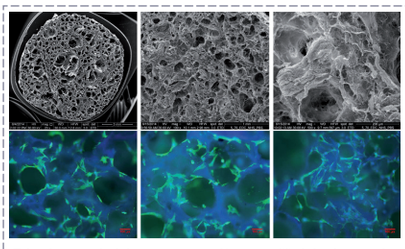
● Isolation and characterization of collagen from various animal genera and sources

T. Suchý, Š. Rýglová, Z. Sucharda, K. Balík, J. Šepitka, J. Lukeš. *Nanoindentation characterisation of poly(DL-lactide)/collagen nanocomposites.* Computer Methods in Biomechanics and Biomedical Engineering 2012; 15(S1):89-90.



Lyophilized collagen isolated from fish and porcine skin.

● Composite scaffolds promoting the regeneration of defective bone tissue with e required rate of safe biodegradation



Biodegradable composite scaffolds based on natural collagen, calcium phosphate nanoparticles, poly(DL-lactide) nanofibers and sodium hyaluronate (SEM images) seeded with mesenchymal stem cells (168 h post seeding).

● Pyrolysed matrix composites for use at elevated temperatures

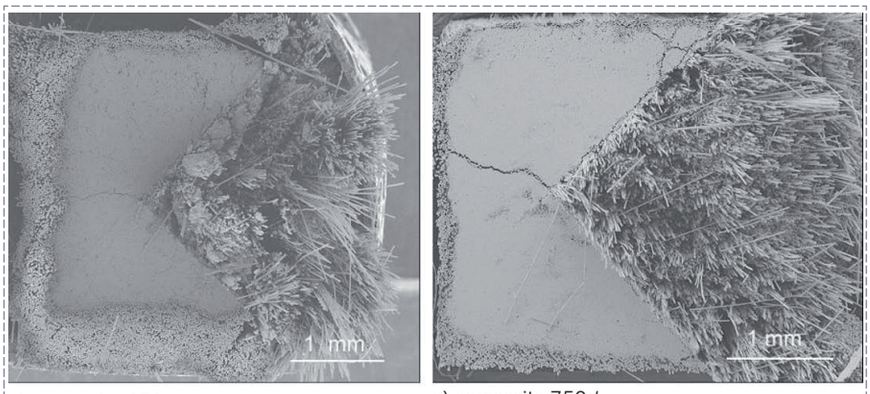
M. Černý, M. Halasová, J. Schweigstillová, Z. Chlup, Z. Sucharda, P. Glogar, J. Svítilová, A. Strachota, Š. Rýglová. *Mechanical properties of partially pyrolysed composites with plain weave basalt fibre reinforcement.* Ceramics International 2014; 40(5):7507-21.

W. Pabst, E. Gregorová, M. Černý. *Isothermal and adiabatic Young's moduli of alumina and zirconia ceramics at elevated temperatures.* Journal of the European Ceramic Society 2013; 33(15-16):3085-93.

M. Halasová, Z. Chlup, A. Strachota, M. Černý, I. Dlouhý. *Mechanical response of novel SiOC glasses to high temperature exposition.* Journal of the European Ceramic Society 2012; 32(16):4489-95.

A. Strachota, M. Černý, Z. Chlup, M. Šlouf, J. Hromádková, J. Pleštil, H. Sandová, P. Glogar, Z. Sucharda, M. Havelcová, J. Schweigstillová, I. Dlouhý, V. Kozák. *Optimization of sol-gel/pyrolysis routes to silicon oxycarbide glasses.* Journal of Non-Crystalline Solids 2012;358(20):2771-82.

M. Černý, P. Glogar, Z. Sucharda, Z. Chlup, J. Kotek. *Partially pyrolyzed composites with basalt fibres - Mechanical properties at laboratory and elevated temperatures.* Composites: Part A 2009; 40(10):1650-59.



a) composite 650c a) composite 750*d*

Partially pyrolysed composites with basalt fibre reinforcement - SEM photographs of the fracture surfaces after the chevron-notch test - material treated at a). 650 °C and at b). 750 °C.

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